PLATE WATER ABSORPTION METHOD FOR BENTONITE EVALUATION AND ITS RELEVANCE TO IRON PELLETIZING PERFORMANCE[1]

Theodore Karidakis[2]

Abstract

Quality of bentonite as a binder is assessed by a variety of laboratory methods. However, the identification of significant correlations between bentonite properties and pelletizing performance has not been possible so far due to the large complexity of interactions between bentonite and iron ore properties. In this article, the suitability and the constraints of plate water absorption method for bentonite characterization as a binder in iron pelletizing was investigated, based on an empirical approach with the use of statistical design and analysis of experiments. Pelletizing performance of two different iron concentrates with three bentonite qualities, differing in their water absorption capacity, measured by the plate method, was studied. It was found that the effect of plate strongly depends on the iron concentrate. Plate water absorption was also considerably affected by hardness of water in the concentrate and conditions of bentonite grinding. Quality assessment of bentonite should, therefore, include not only conventional plate value measurement but also a good estimation of bentonite resistance to water hardness and to the relatively harsh conditions during drying and grinding.

Key words: Bentonite; Pelletizing; Plate method.

1 *Technical contribution to the 2nd International Symposium on Iron Ore, September 22 – 26, 2008, São Luís City – Maranhão State – Brazil*

2 *R&D Researcher, S&B Industrial Minerals, Bentonite Division, 15 A. Metaxa Str. 14564, Kifissia, Greece.*

1 INTRODUCTION

Bentonite is clay consisting almost entirely of smectite minerals, mostly montmorillonite. The clay is usually the product of alteration of volcanic ash, deposited under marine conditions. Bentonite is a valuable mineral due to its unusual physicochemical properties, such as the ability to exchange cations, its hydration and swelling capacity, its binding properties, its impermeability and its rheological properties of viscosity and thixotropy. The range of applications for bentonite is remarkably extensive, although certain qualties of bentonite are particularly suited for certain end –uses.[1]

The role of bentonite in iron pelletizing is to impart strength and plasticity in green pellets, to control their size structure and shape and thus to affect considerably the productivity of the pellet plant. The role of bentonite is equally important during pellet drying and firing, as it affects crucial operating conditions with significant economic implications, such as dust generation and bed permeability. The effect of bentonite on important physico-chemical properties of fired pellets, such as compression strength and reducibility index has been also acknowledged.[2]

The selection of a proper bentonite quality is of primary importance for pellet plants with significant economic and pellet quality implications. A crucial characteristic of bentonite is that its performance does not depend only on the content of smectite but also on the structure and the physicochemical properties of smectite as well as on the presence of other accessory minerals. This characteristic results from different genesis conditions of each specific deposit, creating in this way a large differentiation of bentonite qualities. Therefore, the term 'quality' used for bentonite is not exclusively related with the montmorillonite content (bentonite grade) but with its physicochemical properties and its performance in specific end uses.[3]

The quality of bentonite can be assessed by a variety of laboratory methods. The most common ones are the following: 1. Montmorillonite content, 2. Cation Exchange Capacity, 3. Swelling test, 4. Enslin test, 5. Plate water absorption, 6. Rheological properties of bentonite slurries, 7. Thermogravitometric analysis, 8. Infra Red analysis. Unfortunately, these methods are not fully adequate by themselves for evaluating bentonite in various applications and more specifically in pelletizing. A bentonite may be rated as 'high quality' by various standard tests, yet turns out to be a low quality binder and vice versa. Although some of the methods, like plate value absorption, may provide a fairly good prediction of pelletizing performance, under certain conditions, i.e. stable iron concentrate quality and bentonite of certain origin, it is not possible to find statistical significant correlations over a wide range of values.

So far, very little has been published on the correlation of the physicochemical properties of bentonite with its performance in specific end uses. Stone[4] studied the relation between the zeta potential of bentonite and the strength of pellets and found that zeta potential can be a criterion for bentonite performance as long as it is considered in conjunction with colloid content, i.e. the percentage of montmorillonite, which indicates the quantity of particles that takes part in bonding.

Generally, it has not been possible to reveal correlations between bentonite properties and its pelletizing performance mainly due to a. the large complexity of interactions between bentonite and iron ore properties and b. the effect of interfering factors, such as mineralogical composition of bentonite. Under these conditions, there are no practical benefits for industry in searching mechanistic models that can associate properties of bentonite with pelletizing performance. Bentonite should be rather seen as a material with a bundle of properties interacting with one another rather than a material that can fully described by certain characteristics.

In this article, an empirical approach is proposed, based on statistical design and analysis of experiments. The aim of this research is to identify the pelletizing performance of two different iron concentrates with the use of three bentonite qualities differing in their water absorption capacity, measured by the plate method. Plate water absorption is a property that can provide a relatively good indication of bentonite performance as binder in pelletizing. However, plate absorption is considerably affected by water hardness in the concentrate and conditions of bentonite grinding. Quality assessment should include not only plate value measurement but also a good estimation of bentonite resistance to water hardness and to the relatively harsh conditions during drying - grinding.

2 MATERIALS AND METHODS

For the agglomeration tests, three samples of Greek bentonite, from Milos island were used. The samples were of relatively low, medium and high plate water absorption, covering a range of values commonly used in many pellet plants. Plate was measured according to ASTM E946-83 method, with the exceptions of the sample weight, which was fixed at 0,5 g and the duration of the test, set at 4 hours. Bentonite was ground in a Raymond laboratory mill, hand operated, screw feeder. In Table 1, some of the properties of bentonite samples are shown.

Table 1. Properties of bentonite samples used for agglomeration

Bentonite property	Bentonite A	Bentonite B	Bentonite C
Plate Water Absorption (4h,0,5g) (%)	691	835	933
Swelling (2g/100ml)	31	38	38
Montmorillonite (%)	73,7	85,0	92,3

Two qualities of hematite iron concentrates coming from two different origins were used for the experiments. The grain size distribution characteristics and the specific surface of the concentrates are shown in Table 2.

Table 2. Grain size analysis and specific surface of the iron concentrate samples.

Vol fraction (%)	Concentrate A	Concentrate B
	Undersize (μm)	Undersize (μm)
10	2.76	1,01
50	36.24	28,41
90	138.74	82,70
Mean diameter (μm)	59.83	36,51
Specific surface (m^2/g)	3,8	4,6

For the systematic study of pelletizing results, a full, replicated twice 2X3X3 factorial experiment was carried out. The factors examined were the following: 1. the kind of iron concentrate used, 2. the plate value of bentonite used as binder and 3. the addition rate of bentonite. Table 3 shows analytically the factors studied along with their levels.

Table 3. Full factorial experiment 2X3X3. Levels of factors

LEVELS OF FACTORS	FACTORS		
	A **Type of iron ore**	**B** **Bentonite plate Value (%)**	**C** **Bentonite Addition rate (%)**
0	A	691	0.3
1	B	835	0.5
2		933	0.7

The responses that were statistically studied were the following: 1. Green drop number, 2. Green strength and 3. Dry strength. Moisture level of the green pellets was fixed at 8,5% and was kept constant for all 36 runs of the factorial experiment.

For the pellet preparation, 2,0 Kg of wet iron ore concentrate was spread evenly on a rubber mat, sprinkled with ground bentonite and homogenised in an intensive laboratory mix - muller (e.g. GF / Simpson) for 1 minute and passed twice through a “shredder” for disintegration of the lumps.

Iron concentrate agglomeration was carried out in a balling tire rotated at 50 rpm, with the use of approximately 150 seed – pellets, with diameter -6+4 mesh, for 6 min. Pellets were sprayed with the necessary amount of water so that the final moisture was at 8,5%. After completion of tire balling, pellets were removed from the tire and screened at - 12 + 10mm diameter. The pellets were tested for green drop number and green strength immediately after balling. For the calculation of green drop number, 10 green pellets are separately dropped onto a steel plate from a height of 18" (about 46 cm), until failure occurs. The number of drops producing the failure for each pellet is recorded and then averaged. The results of the green compression strength are recorded as average compression strength of 10 pellets tested on a Chantillon MST-25 machine. The dry compression strength was tested on 10 pellets that had been dried overnight at 105^{o} C. The final result was recorded as an average value.

The effect of water hardness on plate absorption was measured using five bentonite qualities with various initial plate values. The measurement was made with the use of water of various concentrations of calcium and magnesium.

The effect of grinding on the plate value of bentonite was estimated with the use of the above samples with initial moisture levels at 0% and 15%. The thermal resistance of bentonite was measured by TG-DTA analysis in a SETARAM 92-618 apparatus.

3 RESULTS AND DISCUSSION

3.1 Effect of Plate on the Pellet Properties

In Table 4, the results of pelletizing tests of the factorial experiment are presented.

Table 4. Results of the pelletizing tests

Typical Order	Treatment Combination	Factors			Responses		
		Type of Iron Concentrate	Plate value of bentonite	Addition rate of bentonite	Green drop (at 8.5% moisture)	Green strength (kg/p) (at 8.5% moisture)	Dry strength (kg/p)
1	$\alpha_0b_0c_0$	A	691	0.3	5.10 ± 1.20	1.04±0.08	2.51±0.29
2	$\alpha_1b_0c_0$	B	691	0.3	7.90 ± 1.30	1.10±0.13	1.97±0.20
3	$\alpha_0b_1c_0$	A	835	0.3	8.10 ± 1.60	1.22±0.09	3.00±0.31
4	$\alpha_1b_1c_0$	B	835	0.3	9.70 ± 1.29	1.43±0.10	2.98±0.24
5	$\alpha_0b_2c_0$	A	933	0.3	9,70 ± 1.27	1.40±0.08	4.11±0.50
6	$\alpha_1b_2c_0$	B	933	0.3	9.50 ± 1.88	1.56±0.14	3.39±0.29
7	$\alpha_0b_0c_1$	A	691	0.5	10.58 ± 2.13	1.33±0.11	4.54±0.43
8	$\alpha_1b_0c_1$	B	691	0.5	15.58 ± 2.40	1.74±0.10	3.03±0.37
9	$\alpha_0b_1c_1$	A	835	0.5	13.60 ± 1.84	1.74±0.07	5.33±0.44
10	$\alpha_1b_1c_1$	B	835	0.5	16.50 ± 2.54	1.64±0.15	4.34±0.32
11	$\alpha_0b_2c_1$	A	933	0.5	19,00 ± 3.70	1.67±0.11	5.96±0.57
12	$\alpha_1b_2c_1$	B	933	0.5	18,00 ± 3.71	1.89±0.17	5.53±0.44
13	$\alpha_0b_0c_2$	A	691	0.7	14.95 ± 2.40	1.46±0.15	5.59±0.50
14	$\alpha_1b_0c_2$	B	691	0.7	23.70 ± 2.40	1.61±0.11	5.89±0.34
15	$\alpha_0b_1c_2$	A	835	0.7	19.32 ± 2.73	1.63±0.15	6.89±0.82
16	$\alpha_1b_1c_2$	B	835	0.7	24,00 ± 3.64	1.63±0.13	5.47±0.52
17	$\alpha_0b_2c_2$	A	933	0.7	25,00 ± 4.09	1.67±0.11	8.24±0.73
18	$\alpha_1b_2c_2$	B	933	0.7	26.20 ± 3.65	1.76±0.10	6.84±0.90

In order to study the effect of the type of concentrate, the plate of bentonite and its addition rate, an analysis of variance of the 2X3X3 factorial experiment was carried out on pellet properties.

Analysis showed that plate water absorption had statistically significant effect on green drop of pellets produced with concentrate A, while had no effect (in the range of values studied) on the pellets with concentrate B. The existence of an interaction between type of concentrate and plate value of bentonite suggests that plate should be always assessed as a quality index for bentonite in combination with the iron concentrate used for pelletizing. The same conclusions from statistical analysis were drawn for green strength of pellets.

Figure 1 shows the prediction profilers for green drop number versus plate value and addition rate of bentonite for concentrates A and B. In these diagrams, it can be also seen that the effect of bentonite addition rate is higher in the concentrate B. Therefore, for this concentrate, it is the percentage of bentonite used rather than water absorption that determines plastic properties of pellets.

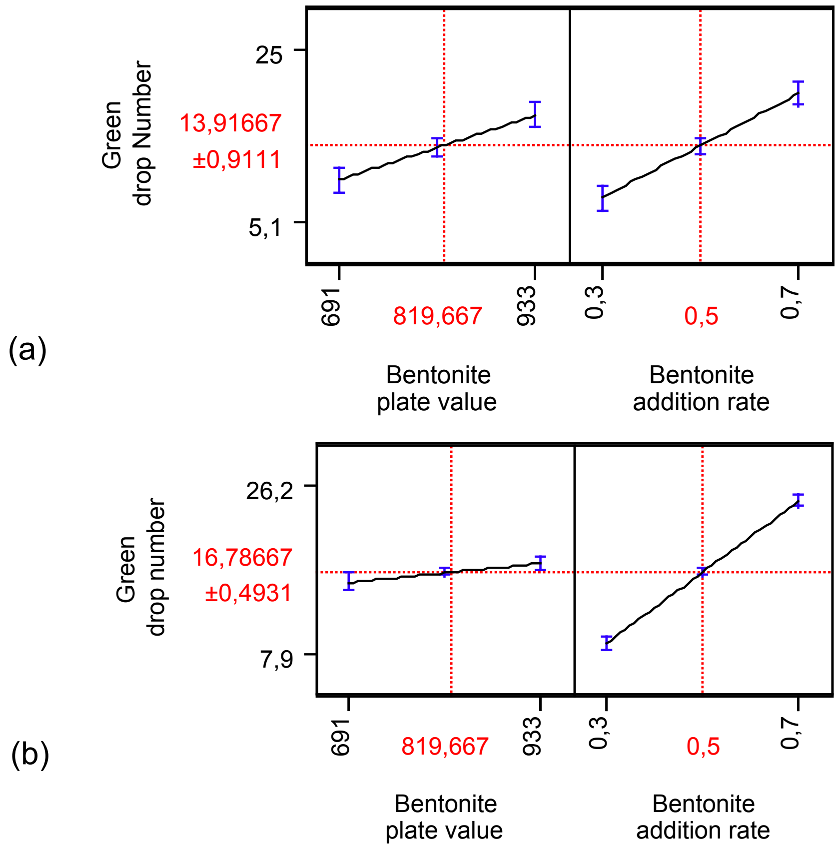

Figure 1. Prediction profilers for green drop number versus plate and addition rate of bentonite for a) concentrate A and b) B

For dry strength, analysis showed that the effect of plate value on both concentrates was statistically significant. However, the effect on concentrate A was higher than in B. For addition rate, the effect on dry strength was again higher in concentrate A. These findings can be also seen in the prediction profilers shown in Figure 2.

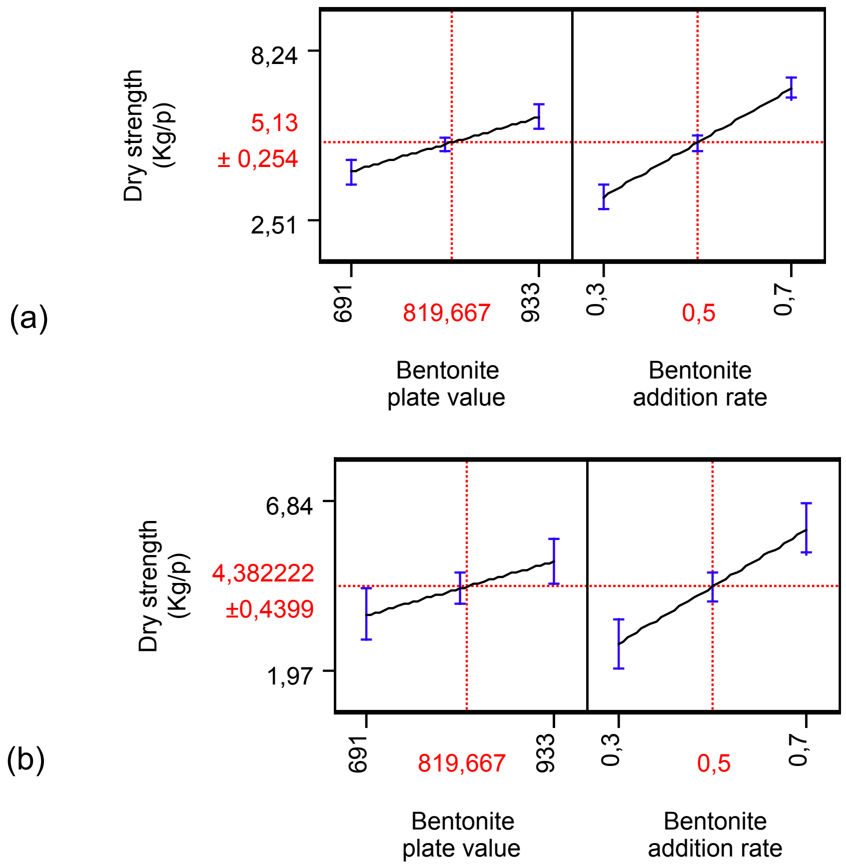

Figure 2. Prediction profilers for dry strength versus plate and addition rate of bentonite for a) concentrate A and b) B

For pellet plants, it is quite important to understand the response of their concentrates to main quality indices of bentonite and especially plate value, which may have a relatively good correlation with pellet properties. Solid interpretation for the different response of the concentrates examined could not be found. A possible reason is the higher amount of fines and very fine material in concentrate B and the higher specific surface area.

It is noteworthy that, for this testwork, factorial experiments and statistical analysis of results is an excellent tool for the accurate estimation of the factors studied and the assessment of experimental errors, which are quite considerable in pelletizing and can easily mislead final conclusions.

3.2 Effect of Water Hardness on Plate Water Absorption of Bentonite

The effect of water chemistry and more specifically of alkaline earth cations, like calcium and magnesium has already been investigated[5]. Calcium and magnesium can replace sodium as exchangeable cations and thus cause serious deterioration in bentonite properties and plate value. The existence of dissolved calcium and magnesium cations in the balling feed water is quite common in pellet plants, at concentrations ranging from few ppm to more than 500 ppm.

Figure 3 shows the effect of calcium and magnesium, at 100 and 300 ppm total concentration, on the plate value of five bentonite samples. The samples 1, 2 and 3 are of sodium activated type and 4 and 5 are of natural sodium type.

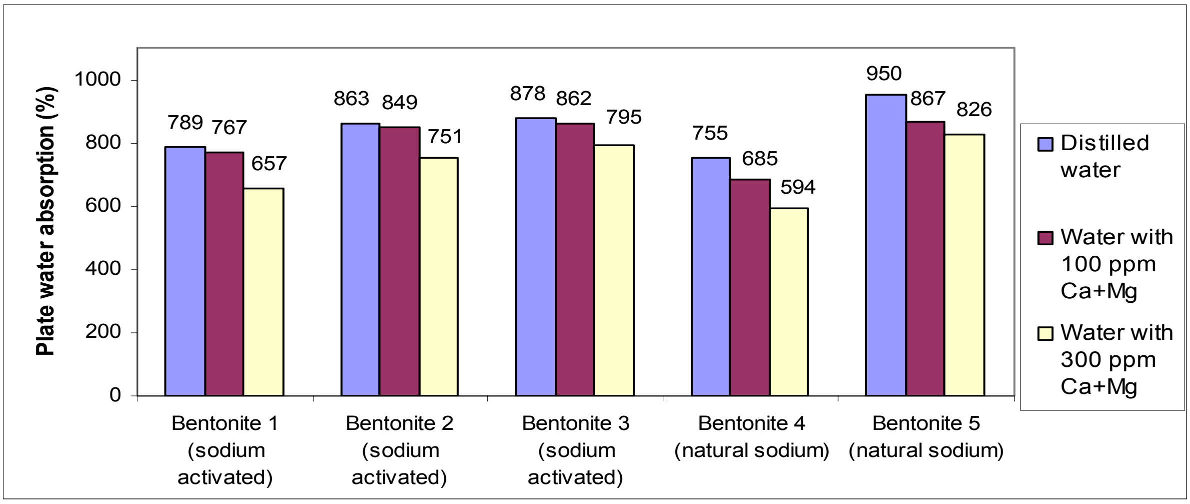

Figure 3. Effect of calcium and magnesium at 100 and 300 ppm concentration levels in the pellet feed water on the plate value of various bentonite qualities.

As shown in Figure 3, not all bentonite qualities had the same resistance to calcium and magnesium cations at the certain concentration levels. At 100 ppm concentration, there was a statistically significant difference in the loss of plate values between samples, ranging from approximately 15 to 85 units. This difference cannot be attributed to the initial water absorption capacity, as samples 2 and 4 with similar values differed considerably in the plate loss.

At 300 ppm concentration of calcium and magnesium, the differences in water hardness sensitivity were lower, with the exception of sample 3, which exhibited significantly higher resistance to alkaline earth cations.

It is obvious that plate method, as applied in the pellet plants, needs to be modified so that it also measures resistance of bentonite to calcium and magnesium, at concentrations similar to the water hardness of the plant water.

3.3 Effect of Grinding on Plate Water Absorption of Bentonite

Conditions of mechanical treatment of bentonite by grinding may cause considerable changes in its properties. These changes result from partial thermal dissociation of montmorillonite and decrease of its crystallinity degree[6]. Conditions of grinding include parameters like initial moisture of granular bentonite, heating and grinding rate, final fineness and moisture of the powder and type of the milling machine.

Initial moisture of bentonite feed material to a mill has been found to play a quite important role in the water absorption capacity of the bentonite powder. Grinding of dry bentonite deteriorates properties of output material affecting negatively plate value.

Figure 4 shows comparison in water absorption capacity of bentonite samples 1-5 that had been ground with initial moisture level 15% and 0%.

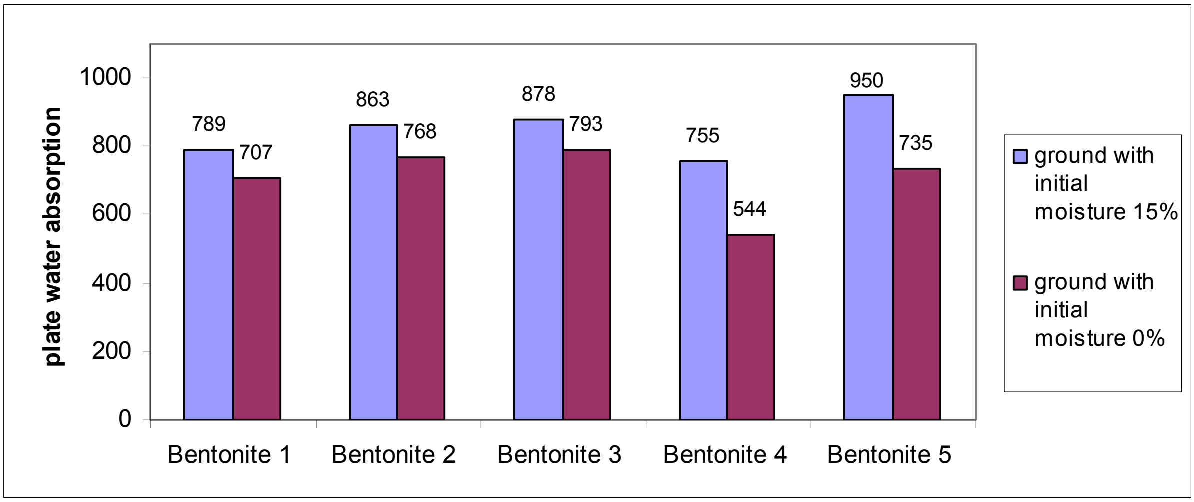

Figure 4. Effect of initial moisture of bentonite prior to milling on the plate values of various bentonite samples.

The effect of initial moisture levels of bentonite prior to milling on plate values was quite considerable. ‘Dry’ grinding of bentonite results in plate decrease that ranges from 80 to 210 units. Results indicate also that there was a significant difference in resistance to ‘dry’ milling between the samples examined. Plate of samples 1-3 decreased by approximately 80-90 units, whereas plate of samples 4 and 5 decreased by approximately 210 units.

Mechanical treatment by grinding has been found to affect stability of the hydroxyl (OH) bonds in the montmorillonite lattice, causing a decrease of the dehydroxylation temperature of bentonite. A bentonite which has low thermal stability becomes more vulnerable to shear stresses and temperature increase, especially under relatively severe conditions of ‘dry’ grinding.

Figures 5 and 6 show TG-DTA thermogram patterns of bentonite samples 1 and 4.

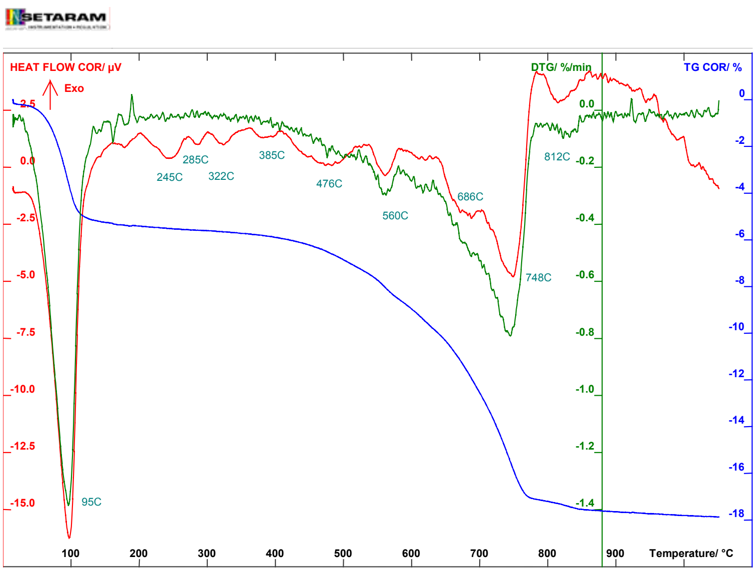

Figure 5. TG-DTA diagram of bentonite with relatively high thermal stability (sample1-3).

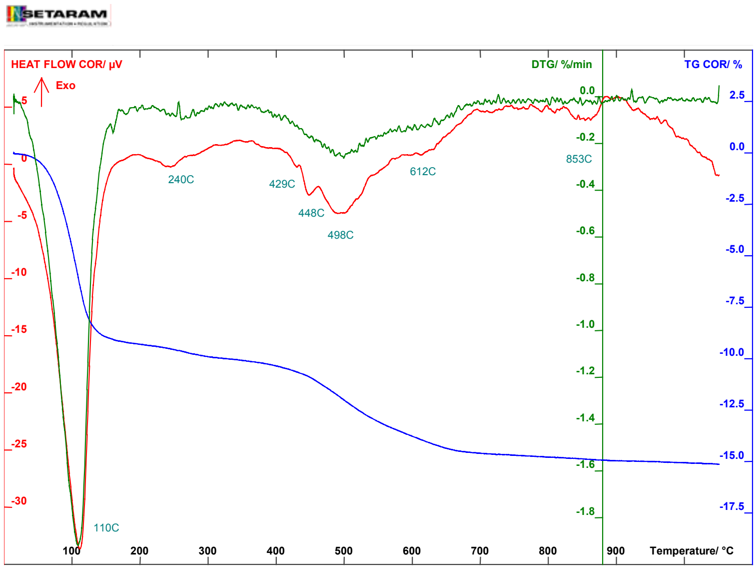

Figure 6. TG-DTA diagram of bentonite with relatively low thermal stability (samples 4,5)

TG-DTA diagrams shown in Figures 5 and 6 differ in the temperature of dehydroxylation of the montmorillonite silicate lattice. For bentonites with fairly high thermal stability, dehydroxylation occurs at temperatures over 650^{o}C, most often in the range 650-750^{o}C, as in the case of samples 1-3, with a strong endotherm peak at 748^{o}C. Bentonites with relatively low thermal stability, present dehydroxylation of montmorillonite at temperatures lower than 600^{o}C, as in the case of samples 4 and 5, with dissociation temperature at 498^{o}C.

The difference in DTA patterns between samples is attributed to the isomorphic substitution of cations that has occurred in the montmorillonite lattice. The Al-OH bonds in the octahedral layer of montmorillonite are stronger than Fe-OH bonds and therefore a large substitution of Al^{3+} by Fe^{3+} cations will cause a decrease in dehydroxylation temperature. The opposite occurs when Mg^{2+} substitutes for Al^{3+}, with the formation of stronger Mg-OH bonds[7].

Thermal stability of bentonite is a quite important property that should be taken into consideration along with water absorption measurement, as can significantly affect important properties of bentonite and therefore pelletizing performance.

4 CONCLUSIONS

The identification of significant correlations between bentonite properties and pelletizing performance has not been possible due to the large complexity of interactions between bentonite and the iron concentrate. Plate water absorption is a relatively good quality index for bentonite. However, for pelletizing application, it should be always evaluated, taking into consideration its effect on a specific iron concentrate and its sensitivity to water hardness and to the usual harsh conditions of milling. In this article, the effect of three bentonite qualities, differing in plate, on two iron concentrates was examined by factorial design and analysis of experiments. It was found that the effect of plate on plastic properties of pellets significantly depends on the quality of iron concentrate. It was also proved that plate water absorption, measured by the conventional method, is not sufficient as it depends on the sensitivity of each bentonite quality to water hardness. Thermal stability of bentonite is an equally important factor, depending on the physicochemical properties of montmorillonite, which affects decrease of water absorption capacity and therefore pellet properties.

REFERENCES

1 GRIMSHAW, R.W. The Chemistry and physics of clays and other ceramic materials. London, Ernest Benn Limited, 1971.
2 RICE, D. Mechanisms of bentonite bonding in iron ore pelletizing, Research Department, Bethelem Steel Corporation, 1979.
3 CHRISTIDIS, G., SCOTT, P. Laboratory evaluation of bentonites. *Industrial Minerals*, August 1993.
4 STONE, R., L. Relation between the zeta potential of bentonite and the strength of unfired pellets. Society of Mining Engineers, Transactions, 1967.
5 ENGESSER, J. The effect of water chemistry, water treatment and blaine on magnetite filtering and magnetite agglomeration with bentonite clay. SME Annual Meeting, Cincinnati, Ohio, Feb.24-26, 2003.
6 PERTOVIC, L, GVOZDENOVIC, L, ANTONIC, S. The effects of the fine grinding on the physicochemical properties and thermal behaviour of bentonite clay. J.Serb.Chem.Soc. 67 (11), p.753-760, 2002.
7 TODOR, D., N. Thermal Analysis of Minerals. Abacus Press, Kent, 1976.